Carbon Nanostructured Advanced Cable Shielding

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ABSTRACT

Applied NanoStructured Solutions, LLC (ANS) has developed a technology to continuously grow and infuse Carbon Nanostructures (CNS) directly onto fiber substrates. ANS has designed and constructed a modular, scalable manufacturing line and demonstrated infusion onto carbon, glass, ceramic, aramid fibers, and metals. This patented method harnesses the advantageous properties of CNS at a cost-effective and commercially viable scale.

ANS, working with TE Connectivity (TE) Advanced Development Group in Menlo Park California, has built several cable products using this technology. Which have applicability in Lockheed Martin (LM) as well other OEM platforms, both defense and commercial. The first form factor built and tested was braided cable shielding. TE manufactured prototype CNS based cables have demonstrated weight savings with acceptable performance. These cables have been flown on a Lockheed Martin platform and met EMP and Lightning requirements for flight safety.

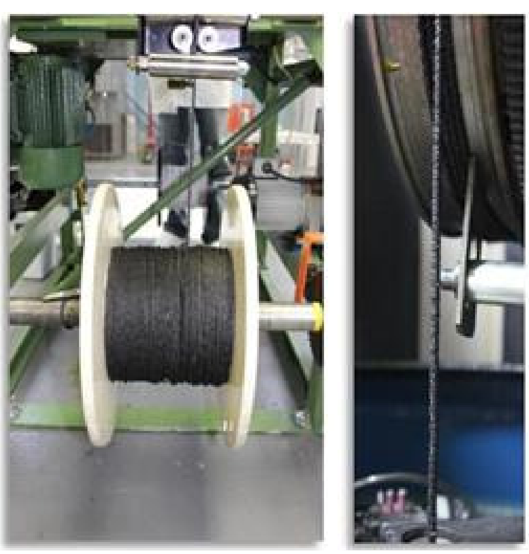

Figure 1: CNS Shielded Cable

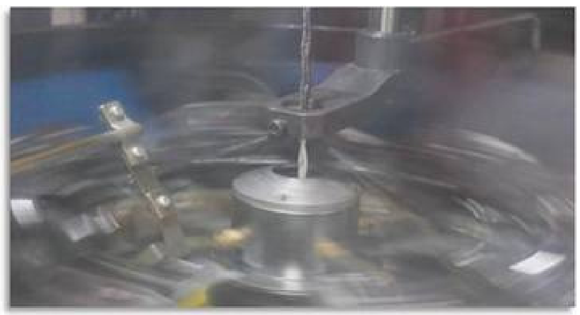

Figure 2: CNS Shielded Cable Under Construction at TE's Menlo Park Facility on an Industrial Braider

CNS-infused weaves demonstrate outstanding EMI shielding performance above 500MHz. Traditional metal braids lose shielding effectiveness as frequency increases due largely to weave apertures in the braid that allow for radio frequency noise penetration. CNS weaves, with near 100% optical coverage exhibit behaviors normally displayed by conductive tubes [1]. At frequencies lower than 100MHz, CNS can be combined with other existing solutions to provide improved performance, weight savings, with potential cost savings.

When CNS-infused glass or carbon fiber is employed as a woven or braided cable shield, the CNS-infused fibers reduce braid apertures to enhance cable EMI shielding performance; the CNS composite can be used across a broad range of cabling applications.

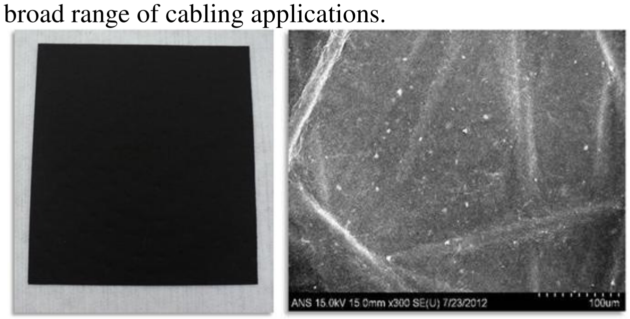

Figure 3: Non woven CNS hybrid system – Near-complete Optical Coverage to the Nano Scale

ANS has recently developed a CNS infused Non Woven Hybrid material. Initial tests demonstrate that the CNS Non Woven Hybrid material provides approximately 45dB of shielding between 30MHz and 8Ghz, weighing only 15 Grams Per Square Meter (GSM). Initial applications for the hybrid are cable shielding, using a tape format and lightweight composite enclosure shielding, using a sheet appliqué.

Keywords: cables, carbon nanostructures, CNS, EMI, Shielding, weight savings,

1 INTRODUCTION

There has always been a need for light weight cable and EMI shielding solutions for defense aerospace, in particular aviation and space applications. In recent years ground vehicles and naval platforms also have been challenged to reduce weight to increase mobility and reduce fuel consumption. Complicating these needs are budget challenges that require reducing cost.

Traditional nano-materials have cost, lead times and resistivity issues that make them unsuitable for all but the most exotic space applications. TE Connectivity and ANS have been working together to solve many of these challenges. The first product form is a CNS braided shield over a traditional copper core. The second is a CNS Non Woven Hybrid (NWH), which has applications in a tape format for cables and as shield layer for enclosures.

2 CNS BRAIDED CABLE SHIELD

CNS can be grown directly on a variety of substrates; the most mature processes use glass and carbon fiber “tow” (yarn) via a continuous reel-to-reel process with a subsequent post coat step.

Spools of the CNS infused tow are transferred onto bobbins suitable for use in industrial braiding equipment.

ANS built the first CNS shielded cables and ran Shielding Effectiveness (SE) testing. These showed promise from 2 to 18GHz. They were less effective at 1Ghz and below.

The effectiveness of the first cables built was limited, as most defense aerospace applications have EMP requirements which are below 1Ghz. Other sub GHz applications include high speed serial data protocols using a base frequency of around 200MHz, terrestrial platforms with lightning requirements, and RF energy cable couplers. In order to address a larger application space, the decision was made to focus on low frequency performance.

Shield performance was evaluated using Surface Transfer Impedance (STI). This is an industry standard method to characterize a cable shield’s performance independent of the cable geometry and is extremely repeatable.

Initial testing showed that the CNS Tow shields had poor low frequency performance, that is, high impedance. As frequency increased, the CNS Tow exhibited behavior similar to metal tubes. Sample spectra, CNS on glass fiber, shown in Figure 4. CNS on Carbon Fiber exhibited similar behavior in all cases.

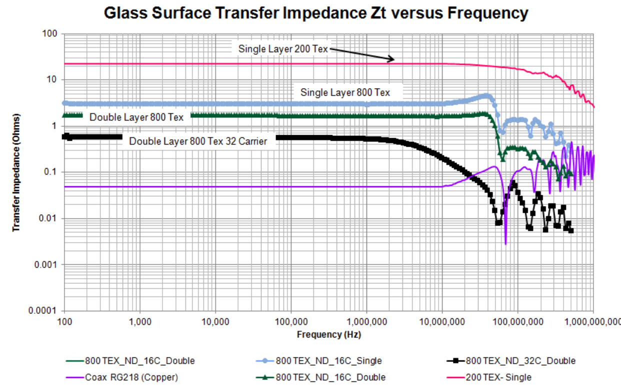

Figure 4: CNS Glass STI Results

Current efforts into conductivity improvement of the CNS construction are ongoing. The challenge is to approach the conductivity of copper while still maintaining cost and scalability goals.

Hybridization of the CNS braid, by adding a small amount of conductive material (e.g. copper) was an obvious first solution.

Figure 5: CNS/Copper Hybrid Shield

As anticipated, the hybrid construction exhibited improved low frequency performance; however at 20KHz impedance began to increase until it matched the performance of the non-metallic original construction..

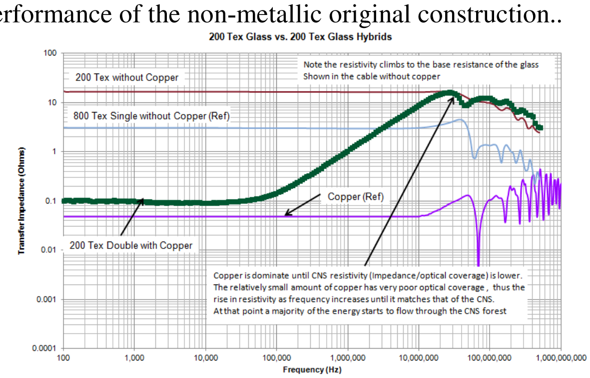

Figure 6: CNS/Copper Hybrid

The initial working hypothesis was that the energy flows through the copper part of the construction at low frequencies and continued to do so through the frequency spectrum until the CNS impedance became lower at approximately 40MHz. Above 20k, prior to the dominance of the CNS impedance term, the minimal optical coverage of the copper failed to provide sufficient shielding[1]. Following on the initial results, remaining constructions were covered with a full copper braid and tested. The expectation was that the initial change in slope would shift to the right due to improved copper optical coverage and then increase until the CNS impedance term dominated. This proved to be false.

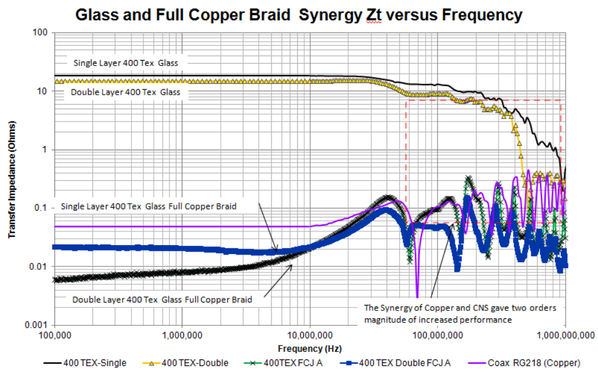

Figure 7: CNS/Full Copper Braid Synergy

The CNS braid saw a two order of magnitude performance increase at the frequency range the CNS is thought to be dominate. For the sake of clarity only two samples are shown, but multiple samples were tested of various Tex (yarn) weights and materials, all demonstrated the same behavior.

The original theory that the impedance of the CNS was the dominate parameter as frequency rises is incomplete. As supported by traditional EMI literature [1], the optical coverage is the key design parameter for improved transfer impedance.

When the CNS/Full copper braid samples were initially prepared, the connector interfaces were configured serially; the CNS was between the copper outer braid and the connector chassis and was tested. They were then reworked so that the CNS was in parallel with respect to the connector chassis and tested (Figure 8).

[1] A metal tube provides 100% optical coverage. Cable braids provide less due to the apertures (openings) where the weaves cross.

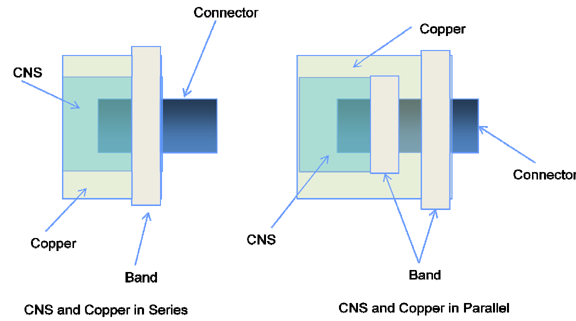

Figure 8: Cable End Configuration

The change in termination improved results dramatically (Figure 9) and has allowed TE/ANS to develop a model to accurately predict the shield behavior.

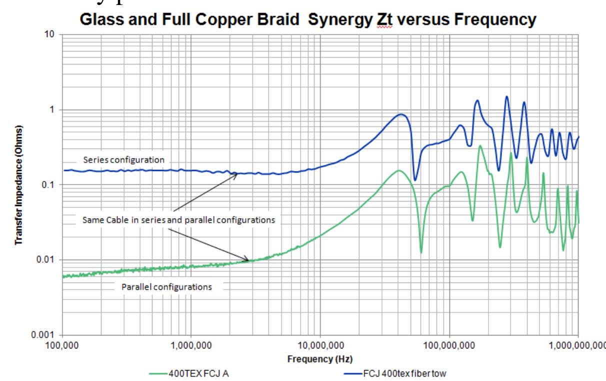

Figure 9: Cable Ends in Series and Parallel Configuration

Most significantly, the optimized cables have undergone flight testing. Traditional copper shielded cables were replaced with CNS/Copper hybrid shielded cables with weight savings between 10% and 20%; the cables met lightning and EMP requirements (Figure 10)

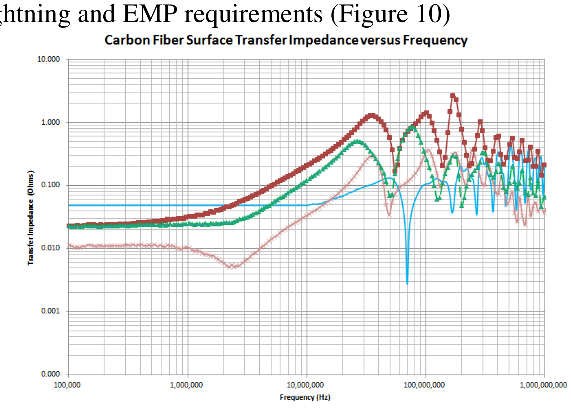

Figure 10: Flight Cable Test Results

3 CNS NON WOVEN HYBRID

Complementing the braided product ANS developed a low cost, extremely light weight CNS Non Woven Hybrid (NWH). The substrate is an off the shelf carbon fiber product with a light metal coating. The CNS is infused onto the substrate. The resultant composite material during initial testing showed relatively low resistivity vs. weight

Parameter	**Value**
Thickness (µm)	60
Sample Mass (mg) (15mm dia.)	2.5
Areal Density / Grams Per Square Meter (GSM)	14.1
In Plane Resistance (Ω/sq) (1"x1")	0.33
Through Plane Resistance (mΩ) (1"^{2}) (@10psi)	7.5
Density (mg/cm^3)	236

Table 1: CNS NWH Measurements

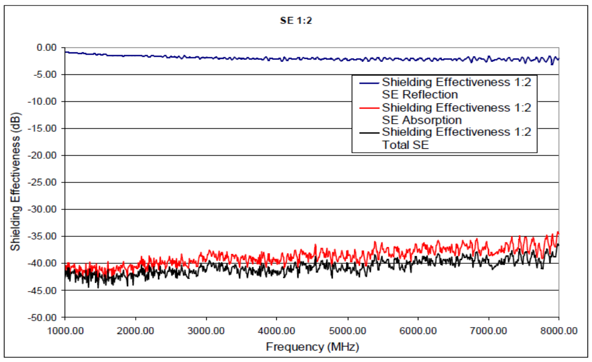

Figure 11: CNS NWH SE Results 1 – 8GHz.

ANS sent samples to TE for further evaluation; due to the small sample size, initial SE testing could only be run on TE's proprietary ASTM 4935 based high frequency fixture. The results of the tests were encouraging based on a trade study of EMI shielding solutions

Sample	Areal Density (GSM)	SE (dB) at 4GHz	Normalized Performance (SE/GSM)
CCNI Spray coated CNT	0.8	27	33.75
CNS NWH	**15**	**40**	**2.67**
Nanocomp sheet (1)	**19**	**44**	**2.32**
CCNI Buckypaper	35	58	1.66
Nanocomp Sheet (2)	40	52	1.3
MTC CuNi/Poly	68	68	1
STM NiAg/Nylon Tafetta	78	60	0.77
STMg/Nylon Loop	125.5	60	0.48
Graf-X®	538.2	70	0.13
Amberstrand®	585	40	0.07
Metallic Over-Braid	3500	50	0.01

Table 2: Light Weight Shield Trade Study Results

Further work was done to increase sample size and full ASTM 4935 Testing (30MHz to 1.5 GHz) was conducted on CNS NWH alone, Two Sheets and with shielded and non-shielded polymers. Overall results were excellent and the CNS NWH can be used to enhance both shielded and unshielded materials.

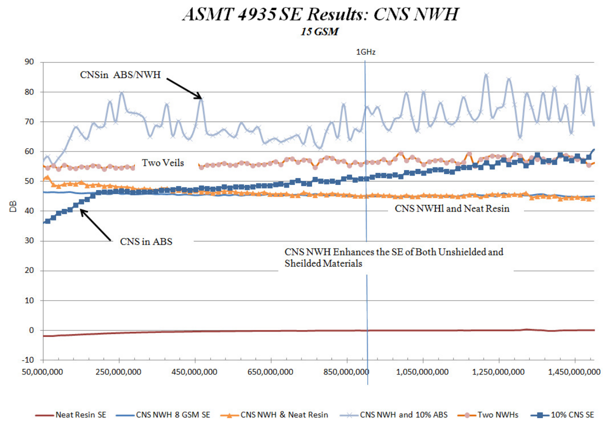

Figure 12: CNS NWH ASTM 4935 SE Test Results

Another interesting property discovered was that CNS NWH does not "leak" energy at the seams. This property lends itself well to efficient cable tapes and encloses appliqué. Testing showed no leakage with only a 2% Overlap

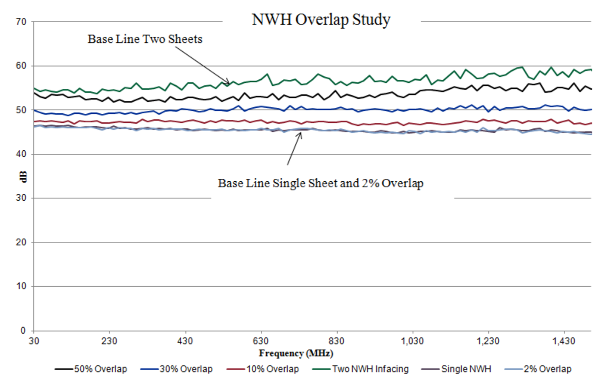

Figure 13: CNS NWH Overlap Study Results

Prototype cables for space applications have been built and industrial scale manufacturing trials of the CNS NWH are in process.

4 CONCLUSION

The synergy of CNS and copper shielding enables the ability to meet existing EMP and lightning requirements while saving as much as 20% of the weight over traditional metal shielded cables. CNS NWH sets new standards for shielding effectiveness vs. weight and cost. The hybrid construction shows extensibility into new form factors, including the CNS NWH which can be produced as a sheet or a tape. TE/ANS are continuing to develop these and other technologies to expand the application space.

REFERENCES

[1] Vance, "Shielding Effectiveness of Braided Wire Shields", Interaction Note 172, 24, 1978